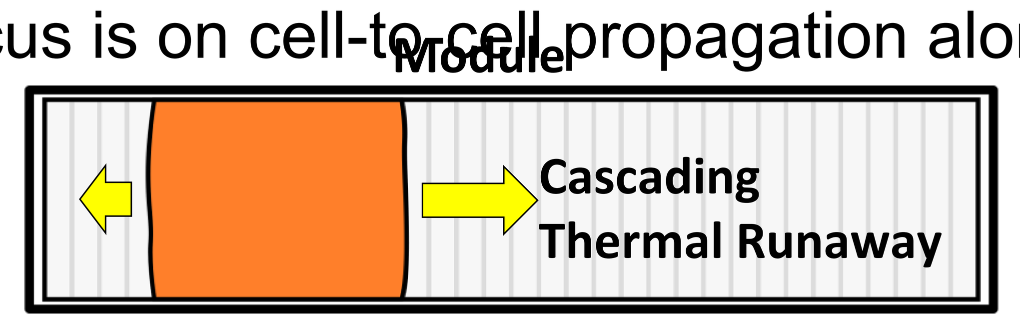
Avoiding cascading failure in battery packs through thermal analysis

John C. Hewson (jchewso@sandia.gov), Andrew Kurzawski, Randy Shurtz, Loraine Torres-Castro
Sandia National Laboratories, PO Box 5800, MS 0836, Albuquerque, NM 87185-0836

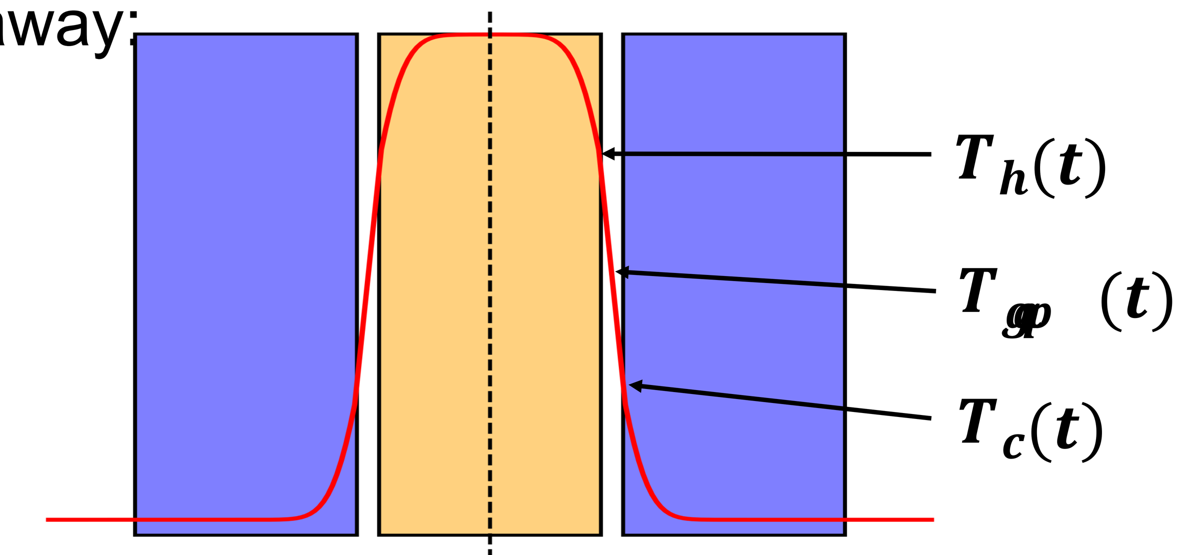
Background

If thermal runaway occurs for lithium-ion cells in a large battery pack, the hazard is dramatically increased if that failure propagates through the pack. This study defines the parameter space for avoiding such propagation.

The focus is on cell-to-cell propagation along a cell stack



Consider a cell that has undergone thermal runaway surrounded by cells that risk thermal runaway:



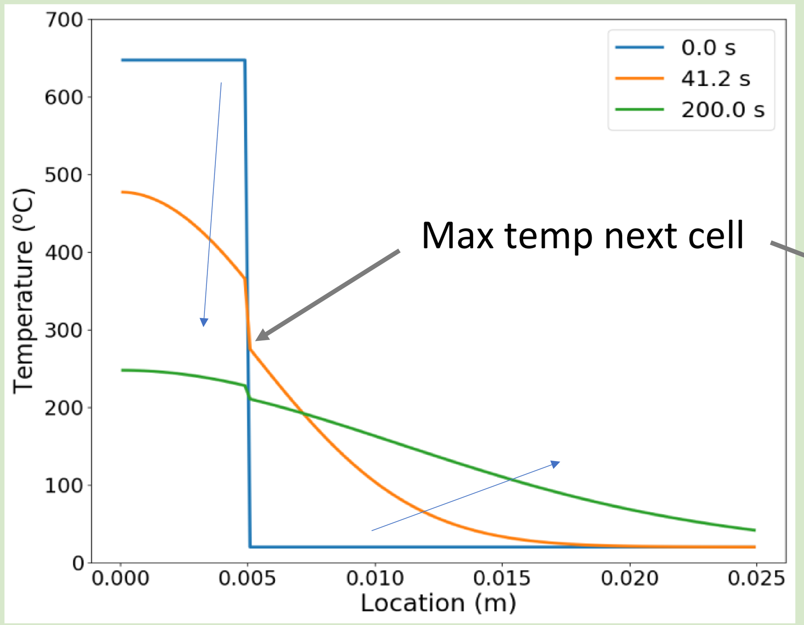
A parameter set for propagation mitigation - I

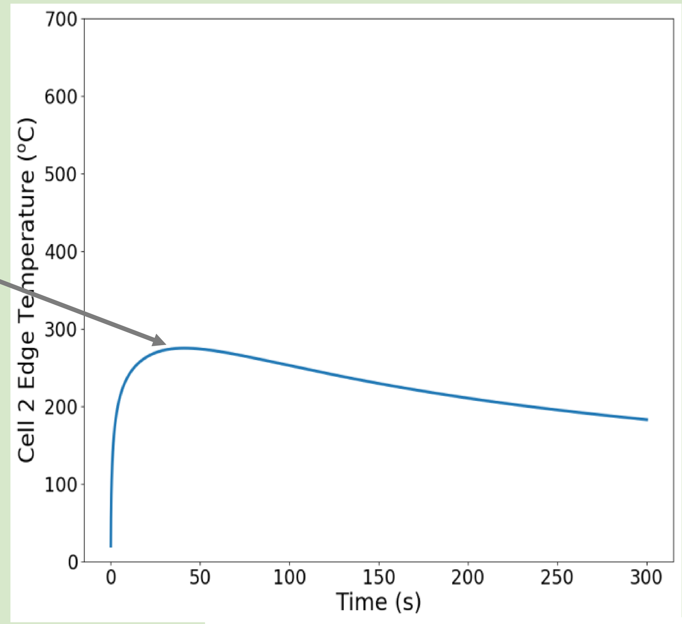
- Cells have a characteristic thermal runaway temperature. Runaway occurs if $\boldsymbol{T_c(t) > T_{TR}}$.
- Some temperature reduction can be achieved by inert material between cells (ex: structure, casing).
- Ex: The heat capacity ratio of inert spacer material to cells is:

$$\phi_{capacity} = \frac{(\rho c_p \delta)_{spacer}}{(\rho c_p L)_{cell}}$$

A parameter set for propagation mitigation - II

- For this analysis focus on heat transfer along stack and to surroundings (structural and/or cooling system).
- Between cells is a thermal resistance, $R''_{contact}$, from packaging and contact.

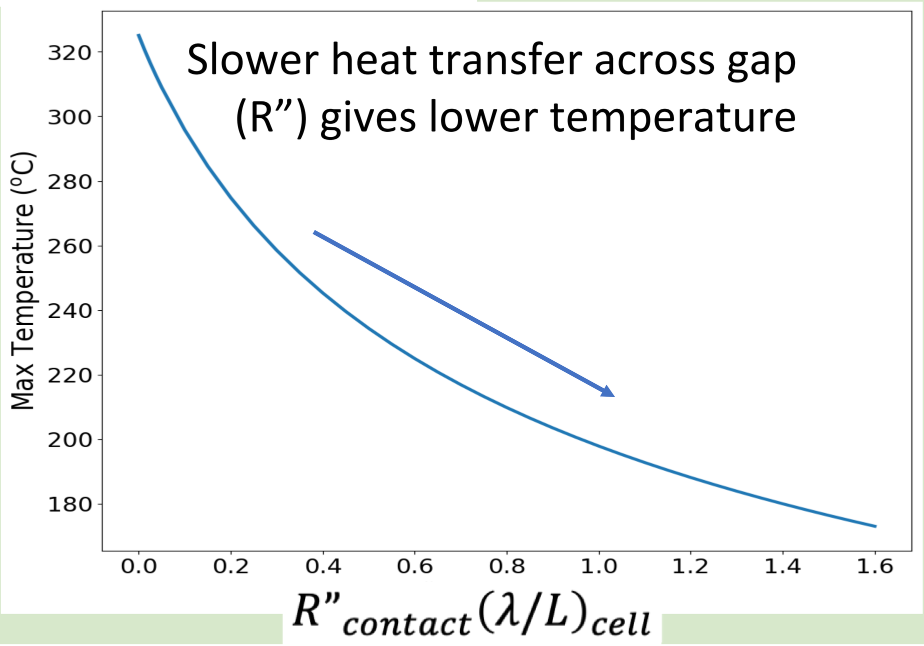




Thermal evolution of $\boldsymbol{T_c(t)}$ (Heat release turned off)

Max temp of next cell depends on

$$\frac{1}{Bi} = \frac{R''_{contact}}{(L/\lambda)_{cell}} = \frac{R''_{contact}}{R''_{cell}}$$



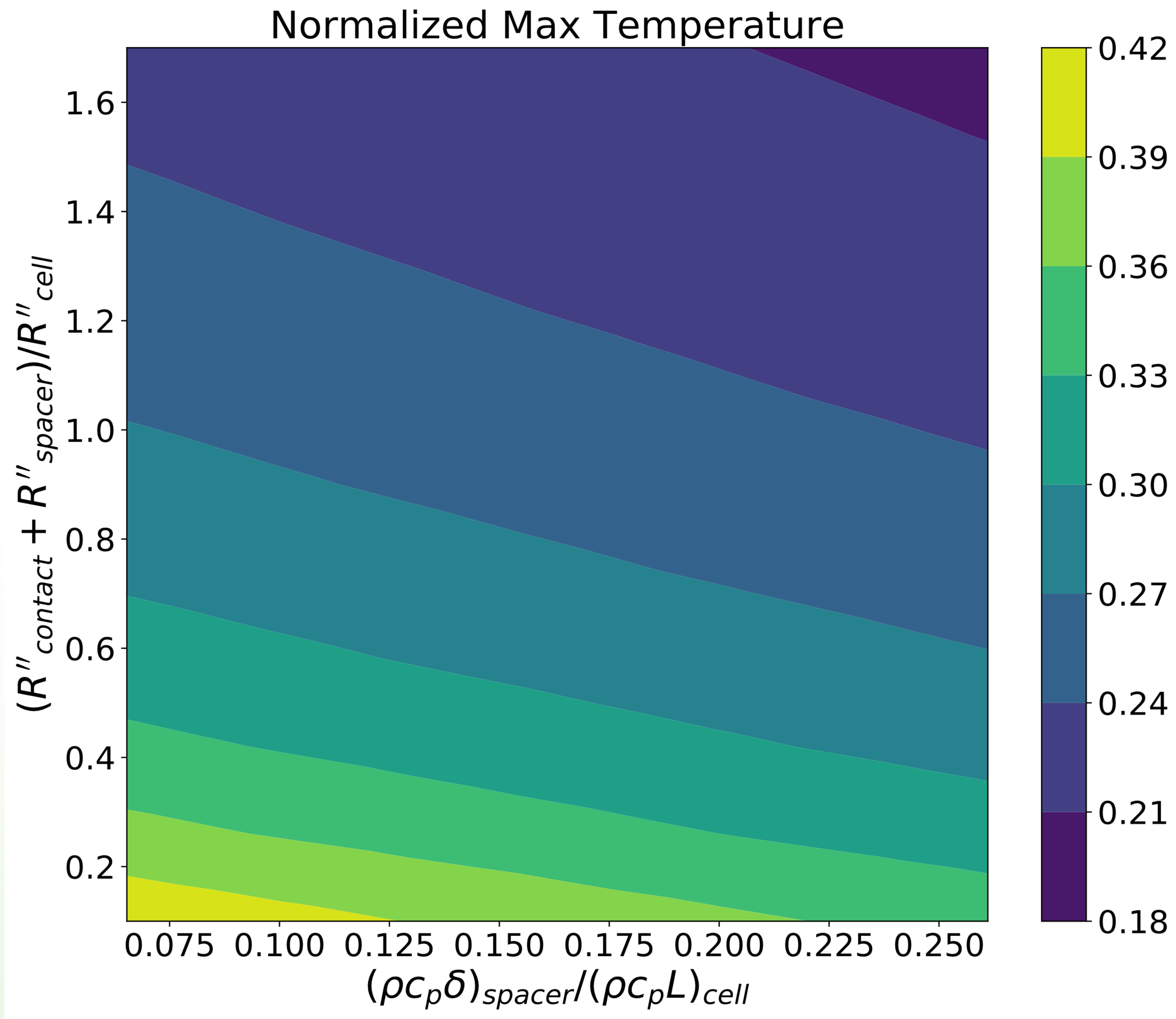
- Ratio of temperature rise to get thermal runaway, ΔT_{TR}, to the temperature rise of initiating cell, $T_{h,0} - T_{c,0}$.

$$\theta_{TR} = \frac{\Delta T_{TR}}{T_{h,0} - T_{c,0}}$$

- Normalize max temperature of target cell similarly:

$$\theta_{max} = \frac{T_{c,max} - T_{c,0}}{T_{h,0} - T_{c,0}}$$

θ_{max} contours



No propagation if: $\theta_{max} < \theta_{TR}$

Summary

Non-dimensional parameters can be used to describe heat flows.

- Thermal conduction: $\frac{1}{Bi} = \frac{R''_{contact}}{(L/\lambda)_{cell}}$
- Heat capacity: $\phi_{struct} = \frac{(\rho c_p \delta)_{struct}}{(\rho c_p L)_{cell}}$
- TR temp over heat release: $\theta_{TR} = \frac{\Delta T_{TR}}{T_{h,0} - T_{c,0}}$
- Propagation criteria: $\theta_{max}(Bi, \phi_{struct}, T_{h,0} - T_{c,0}) < \theta_{TR}$

- Heat must be removed before thermal runaway onset 150~200°C.
- Heat transfer parameters are critical for system design.

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.
SAND No. ___________